

# One-step synthesis and structure of a tricyclic trislactone with $C_3$ symmetry<sup>†</sup>

Remir G. Kostyanovsky,<sup>\*a</sup> Oleg N. Krutius,<sup>a</sup> Andrey A. Stankevich,<sup>b</sup> Lev V. Vilkov,<sup>c</sup> Evgenii G. Atavin,<sup>d</sup> Yuriy V. Vishnevsky<sup>c</sup> and Arkadii A. Ivanov<sup>c</sup>

<sup>a</sup> N. N. Semenov Institute of Chemical Physics, Russian Academy of Sciences, 119991 Moscow, Russian Federation.

Fax: +7 095 651 2191; e-mail: kost@chph.ras.ru

<sup>b</sup> Higher Chemical College, Russian Academy of Sciences, 125047 Moscow Russian Federation. Fax: +7 095 200 4204

<sup>c</sup> Department of Chemistry, M. V. Lomonosov Moscow State University, 119992 Moscow, Russian Federation.

Fax: +7 095 932 8846; e-mail: LVVilkov@phys.chem.msu.ru

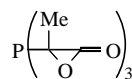
<sup>d</sup> Department of Chemistry, Omsk State University, 644077 Omsk, Russian Federation. E-mail: atavin@univer.omsk.su

DOI: 10.1070/MC2004v014n03ABEH001929

The reaction of piruvic acid with  $\text{PH}_3$  in the presence of  $\text{HCl}$  leads to the self-assembly of chiral tricyclic trislactone **1**, the structure of which is proved by spectroscopy and gas electron diffraction.

The chiral molecules of  $C_2$ ,<sup>2,3</sup>  $C_3$ <sup>4–6</sup> and higher order symmetries are aesthetically pleasing and very interesting for different fields of chemistry.

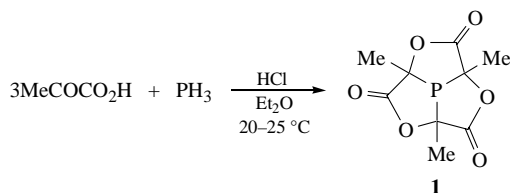
Previously, we developed the methodology of configurationally and conformationally controlled self-assembly of bicyclic bislactones and bislactams of  $C_2$  symmetry.<sup>2</sup> These bislactones were synthesised for the first time by N. D. Zelinskii (1890).<sup>2,7</sup> Our methodology can also be useful for the synthesis of polylactones of higher symmetry. A similar trislactone was obtained even earlier (1888).<sup>8</sup> However, it was initially described without structure;<sup>8(a)</sup> then, as a tris- $\alpha$ -lactone<sup>8(b)</sup>



and, finally, as tris- $\gamma$ -lactone **1** (1960)<sup>8(c)</sup> (Scheme 1). In 1972, it was found<sup>9</sup> that  $\alpha$ -lactones are stable only at temperatures lower than  $-100^\circ\text{C}$  (see ref. 10, p. 130).

Surprisingly, neither the beautiful molecules of Zelinskii dilactones nor trislactone **1** were described in reviews,<sup>3–6</sup> a monograph on lactones<sup>10</sup> or textbooks on organic chemistry and stereochemistry.

In this study, we reproduced the synthesis<sup>8</sup> of trislactone **1** (Scheme 1).<sup>‡</sup>



Scheme 1

The product exhibited the same properties (including mp) as that in ref. 8, where elemental analysis, perfectly corresponding to **1**, IR spectrum ( $\nu_{\text{CO}}$   $1784\text{ cm}^{-1}$ ) and other proof for the reported structure **1** was provided. The  $C_3$  symmetry of the molecule is proved by  $^1\text{H}$  NMR (methyl protons doublet,  $^3J_{\text{HP}}$  corresponds to tertiary phosphine),  $^{13}\text{C}$  NMR (the equivalency of carbons of three Me, three CP and three CO groups) and  $^{31}\text{P}$  NMR spectra (decet with  $^3J_{\text{PH}} = ^3J_{\text{HP}}$ ).<sup>‡</sup> According to mass spectrometry,<sup>‡</sup> the molecular mass of **1** is consistent with that found by ebullioscopy.<sup>8(c)</sup> Crystallization of **1** from different solvents or sublimation failed to give single crystals suitable for X-ray analysis. We failed to obtain an oxide of **1** by the treatment of **1** with 50%  $\text{H}_2\text{O}_2$ . It was previously mentioned<sup>8(c)</sup> that **1** is stable towards anhydrous peroxides, sulfur and  $\text{MeI}$  in aprotic solvents, whereas the treatment with  $\text{MeI}$  in  $\text{MeOH}$  gives the phosphonium iodide  $\text{Me}_3\text{P}^+\text{C}(\text{Me})(\text{OH})\text{CO}_2\text{MeI}^-$ . However, easy sublimation of **1** at  $100^\circ\text{C}$  (3–4 Torr) allowed us to determine its molecular structure by gas electron diffraction.<sup>§</sup>

<sup>†</sup> Self-assembly of cage structures. Part 16, previous communication see ref. 1.

**Table 1** Experimental (a) and theoretical calculated (b) structure parameters of **1** (distances  $r_g$  in Å, angles  $\angle_\alpha$ , deg, 1...10 – parameter groups).

	a		U		b	
C–H	1.096 <sub>ass</sub>	1.0960	0.076	CCC	111.0(4) <sup>6</sup>	110.9
C=O	1.200(4) <sup>1</sup>	1.1995	0.037	PCMe	115.9(4) <sup>6</sup>	115.8
$\text{C}_{\text{sp}^2}\text{--O}$	1.359(5) <sup>2</sup>	1.3603	0.047	$\text{CC}_{\text{sp}^2}\text{O}$	112.3(6) <sup>7</sup>	114.2
$\text{C}_{\text{sp}^3}\text{--O}$	1.452(6) <sup>3</sup>	1.4494	0.051	COC	118.7(6) <sup>8</sup>	118.7
$\text{C}_{\text{sp}^3}\text{--Me}$	1.527(4) <sup>4</sup>	1.5200	0.051	OCO	122.6(6) <sup>8</sup>	121.6
$\text{C}_{\text{sp}^2}\text{--C}_{\text{sp}^3}$	1.557(4) <sup>4</sup>	1.5503	0.053	$\text{PCC}_{\text{sp}^2}$	107.8(4) <sup>9</sup>	106.8
C–P	1.891(5) <sup>5</sup>	1.8944	0.054	CCH	108.(4.) <sup>10</sup>	110.0
	$R_f = 6.9\%$			CCOC	5.27 <sub>ass</sub>	5.27

The molecular structure of **1** was described by five groups of internuclear distances (C=O,  $\text{C}_{\text{sp}^2}\text{--O}$ ,  $\text{C}_{\text{sp}^3}\text{--O}$ , C–C and C–P), small differences for which were taken from quantum-chemical calculations (B3LYP/6-31G\*\*, Table 1), as well as five groups of bond angles (CCC and PCMe,  $\text{CC}_{\text{sp}^2}\text{O}$ , COC and OCO,  $\text{PCC}_{\text{sp}^2}$ , CCH). The correlation coefficients between the parameter groups formed were lower than 0.84. The inner rotation angle of a practically planar fragment of the five-membered ring C–C–O–C is fixed on the quantum-chemical value. For the methyl groups  $\text{C}_{3v}$ , local symmetry was assumed.

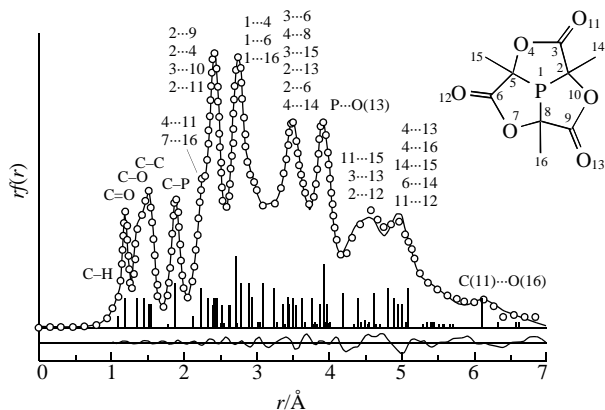
<sup>‡</sup>  $\text{PH}_3$  was obtained<sup>8(c),11</sup> by the pyrolysis of crystalline  $\text{H}_3\text{PO}_3$  on heating to  $175\text{--}200^\circ\text{C}$  (0.5 h),  $205\text{--}210^\circ\text{C}$  (0.5 h),  $350^\circ\text{C}$  (1 h) and collecting to a trap cooled with liquid nitrogen, yield ~95%.

**1**, trislactone of phosphatris(2-hydroxy-2-methylacetic acid) or all-*cis*-1,4,7-trimethyl-3,6,9-trioxa-10-phosphatricyclo[5.2.1.0<sup>4,10</sup>]decane-2,5,8-trione. Through a solution of 4 g of piruvic acid in 50 ml of dry  $\text{Et}_2\text{O}$ , a mixture of  $\text{PH}_3$  and dry  $\text{HCl}$  was bubbled for 3 h at  $20\text{--}25^\circ\text{C}$ , the mixture was allowed to stand for 3 days at  $20^\circ\text{C}$ . The solid product was separated by filtration and dried; yield, 2.1 g of **1** (56%). Crystallization from glacial acetic acid yielded thin needles of **1** with mp  $273\text{--}274^\circ\text{C}$  (lit.,<sup>8(c)</sup> mp  $273\text{--}274^\circ\text{C}$ ) soluble in acetone, MeCN and alcohols; limited solubility in  $\text{CHCl}_3$ ,  $\text{Et}_2\text{O}$  and poor solubility in  $\text{C}_6\text{H}_6$ . **1** is stable to atmospheric oxidation, does not change upon sublimation ( $200\text{--}250^\circ\text{C}$ ) at atmospheric and reduced (1 Torr) pressures at  $100^\circ\text{C}$ . Mass spectrum (EI, 70 eV),  $m/z$  (rel. int., %): 244 ( $\text{M}^+$ , 0.06), 130 (65.6), 129 (21.0), 117 (8.8), 103 (13.5), 87 (49.6), 58 (18.3), 57 (35.5), 56 (15.0), 44 (16.0), 43 (100).  $^1\text{H}$  NMR (400.13 MHz,  $\text{CDCl}_3$ )  $\delta$ : 1.97 (d, Me,  $^3J_{\text{HP}}$  14.3 Hz).  $^{13}\text{C}$  NMR (50.32 MHz,  $[\text{D}_6]\text{acetone}$ )  $\delta$ : 22.7 (dq, Me,  $^3J_{\text{CP}}$  25.4 Hz,  $^1J_{\text{CH}}$  131.3 Hz), 83.8 (dq, CP,  $^1J_{\text{CP}}$  30.0 Hz,  $^2J_{\text{CH}}$  4.4 Hz), 172.0 (d, CO,  $^2J_{\text{CP}}$  4.5 Hz).  $^{31}\text{P}$  NMR (81 MHz,  $[\text{D}_6]\text{acetone}$ )  $\delta$ :  $-22.0$  (decet, P,  $^3J_{\text{PH}}$  14.3 Hz), chemical shift in higher field from 85%  $\text{H}_3\text{PO}_4$ .

<sup>§</sup> Gas electron diffraction of the sample of **1** obtained by sublimation at  $100\text{--}150^\circ\text{C}$  (1 Torr), was studied on an ER-100M instrument.

At a nozzle temperature of  $180^\circ\text{C}$ , an accelerating voltage of 60 kV and two nozzle-plate distances (361.84 and 196.00 mm) at each distance three electron diffraction patterns of **1** were recorded. Simultaneously, the electron diffraction patterns of a standard compound ( $\text{CCl}_4$ ) were recorded for the refinement of the wavelength of scattered electrons and treated according to a published procedure<sup>12</sup> on a UMAX Astra-4500 scanner.

The range of experimental intensities for  $s$  [ $s = (4\pi/\lambda)\sin(\theta/2)$ ;  $\theta$  is the scattering angle and  $\lambda$  is the electron wavelength] was  $5.0 \leq s \leq 17.0\text{ \AA}^{-1}$  for a longer nozzle-plate distance and  $8.6 \leq s \leq 32.2\text{ \AA}^{-1}$  for a shorter distance, respectively.



**Figure 1** The radial distribution curve for **1** (circles represent experimental data, solid line is theoretical, vertical lines correspond to inter-nuclear distances in the molecule).

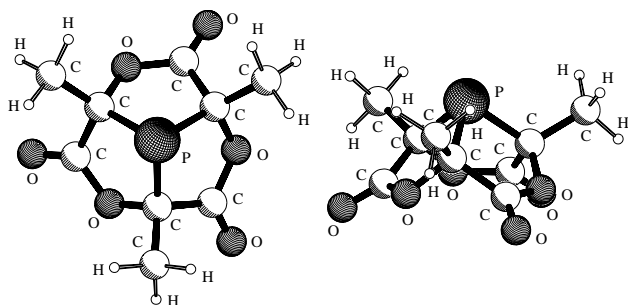
The tests allowed us to exclude alternative variants of the mutual orientation of the fragments of the molecule, differing in the values of inner rotation angles.

The vibrational amplitudes and corrections for the contraction effect were calculated according to a published procedure<sup>13</sup> using quantum-chemical force field. For optimised parameters, the triple RMSD is given in parentheses.

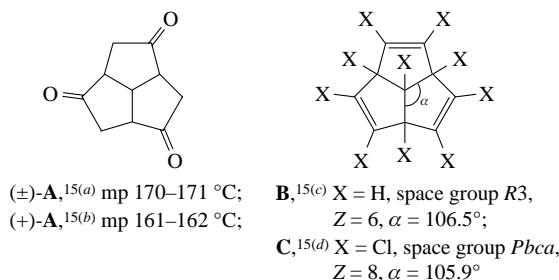
The experimental data are in good agreement with the calculations (Table 1). The agreement between the model of **1** and the experiment is shown on the radial distribution curve (Figure 1). The molecule has  $C_3$  symmetry (Figure 2).

The five-membered rings are distorted and are essentially planar (the sum of inner bond angles is equal to  $537^\circ$ ). The C–P–C angle ( $89.5^\circ$ ) is strongly contracted in comparison with that of other phosphines ( $98.8^\circ$  in  $\text{Me}_3\text{P}$  and  $96.1^\circ$  in 1-phospha-3,5,7-triazaadamantane<sup>14</sup>). Note increased values of the in-cycle bond angles C–O–C [ $118.7(6)^\circ$ ] and C–C<sub>sp<sup>2</sup></sub>–O [ $112.3(6)^\circ$ ] and C<sub>sp<sup>2</sup></sub>–C<sub>sp<sup>3</sup></sub> bond lengthening to 1.557(4) Å (the typical value for the C<sub>sp<sup>2</sup></sub>–C<sub>sp<sup>3</sup></sub> bond length for cyclic ketones is equal to 1.51 Å), which reflect the stress in five-membered rings. The C–P bond [1.891(5) Å] is longer than that in other phosphines [1.844(3) Å in  $\text{Me}_3\text{P}$  and 1.857(3) Å in 1-phospha-3,5,7-triazaadamantane<sup>14</sup>]. The Me–C–P bond angle [ $115.9(4)^\circ$ ] is higher than a typical value of  $109.5^\circ$  for tetrahedral carbon. Other geometrical parameters (C<sub>sp<sup>2</sup></sub>–O, C<sub>sp<sup>3</sup></sub>–O, C=O and C–H<sub>3</sub>) are characteristic of similar acyclic and cyclic molecules with such bond types.

The carbon analogues of trislactone **1** are unknown. The closest structural analogues, triquinacenes A–C (Scheme 2), in contrast to **1**, were obtained by multistep syntheses.<sup>15</sup> Based on a comparison of the mp of (±) and (+)-A, it is possible to assume that the compound crystallises as a true racemate, as well as B, C. X-ray diffraction data on B, C show, similarly to **1**, a significant contraction of bond angle  $\alpha$  (Scheme 2).



**Figure 2** The molecular structure of **1**.



**Scheme 2**

We are grateful to Yu. V. Nekrasov for the measurement of mass spectra and to A. V. Ignatenko for the measurement of  $^{13}\text{C}$  NMR spectra. This work was supported by the Russian Academy of Sciences, the Russian Foundation for Basic Research (grant no. 03-03-32019), RFBR-NNIO (grant nos. 03-03-04010 and 03-03-04004) and the Presidential Programme for Leading Russian Scientific Schools (grant no. 1275.2003.3).

## References

- 1 D. A. Lenev, K. A. Lyssenko and R. G. Kostyanovsky, *Eur. J. Inorg. Chem.*, 2003, 2979.
- 2 R. G. Kostyanovsky, in *Kislород- i serusoderzhashie geterotsikly*, ed. V. G. Kartsev, IBS Press, Moscow, 2003, vol. 1, pp. 295–305 (*Oxygen- and Sulfur-containing Heterocycles*, 2003, vol. 1, pp. 268–278).
- 3 J. K. Whitesell, *Chem. Rev.*, 1989, **89**, 1581.
- 4 C. Moberg, *Angew. Chem., Int. Ed. Engl.*, 1998, **37**, 248.
- 5 M. Nakazaki, *Top. Stereochem.*, 1984, **15**, 199.
- 6 M. Farina and C. Morandi, *Tetrahedron*, 1974, **30**, 1819.
- 7 N. D. Zelinskii, *Chem. Ber.*, 1891, **24**, 4006.
- 8 (a) J. Messinger and C. Engels, *Chem. Ber.*, 1888, **21**, 236; (b) J. Messinger and C. Engels, *Chem. Ber.*, 1888, **21**, 2919; (c) S. A. Buckler, *J. Am. Chem. Soc.*, 1960, **82**, 4215.
- 9 O. L. Chapman, P. W. Wojtkowski, W. Adam, O. Rodrigues and R. Rucktäschel, *J. Am. Chem. Soc.*, 1972, **94**, 1365.
- 10 M. A. Ogliaruso and J. F. Wolfe, *Synthesis of Lactones and Lactams (Updates from the Chemistry of Functional Groups)*, eds. S. Patai and Z. Rappoport, John Wiley & Sons, Chichester, New York, Brisbane, Toronto, Singapore, 1993.
- 11 *Inorganic Synthesis*, ed. S. Y. Tyree, Jr., McGraw-Hill, Inc., New York, 1967, vol. IX, ch. V, p. 56.
- 12 E. G. Atavin and L. V. Vilkov, *Instruments and Experimental Techniques*, 2002, **45**, 27.
- 13 V. A. Sipachev, *J. Mol. Struct. (Theochem)*, 1985, **121**, 143.
- 14 E. Fluck, J.-E. Förster, J. Weidlein and E. Hädicke, *Z. Naturforsch.*, 1977, **32b**, 499.
- 15 (a) E. Carceller, M. L. Garcia, A. Moyano, M. A. Pericas and F. Serratos, *Tetrahedron*, 1986, **42**, 1831; (b) C. Almansa, A. Moyano and F. Serratos, *Tetrahedron*, 1988, **44**, 2657; (c) E. D. Stevens, J. D. Kramer and L. A. Paquette, *J. Org. Chem.*, 1976, **41**, 2266; (d) B. Aurivillius and G. Malmros, *Acta Chem. Scand.*, 1973, **27**, 3167.

Received: 26th April 2004; Com. 04/2255